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(54) **MILLIMETER-WAVE CIRCUIT WITH DIELECTRIC LENS**

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H01Q 19/30 (2006.01)

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CPC ***H01Q 15/08*** (2013.01); ***G01S 13/56*** (2013.01); ***H01Q 19/30*** (2013.01)

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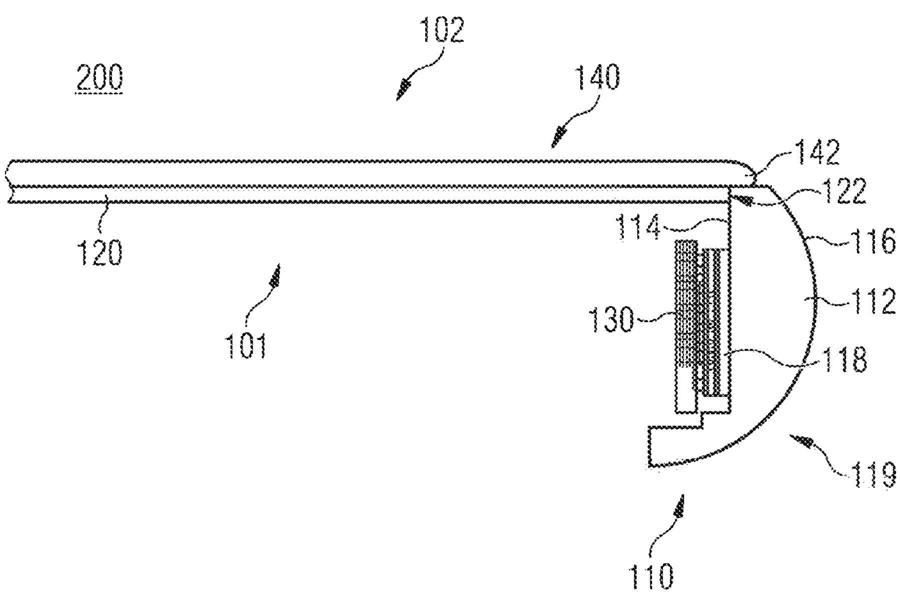
(57) **ABSTRACT**

An electronic device includes a housing, an electrically conductive layer and millimeter-wave (mmw) circuitry configured to emit a mmw signal. The mmw circuitry is arranged in the housing and on a first side of the electrically conductive layer. The housing comprises at least one portion configured as a dielectric lens to refract the mmw signal at least partially outside the housing towards a second side opposite to the first side of the electrically conductive layer.

23 Claims, 11 Drawing Sheets



(58) **Field of Classification Search**
CPC G01S 13/56; G01S 7/028; G01S 13/86; G01S 13/88; G06F 1/1684; G06F 1/1698; G06F 3/017
See application file for complete search history.

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FIG. 1

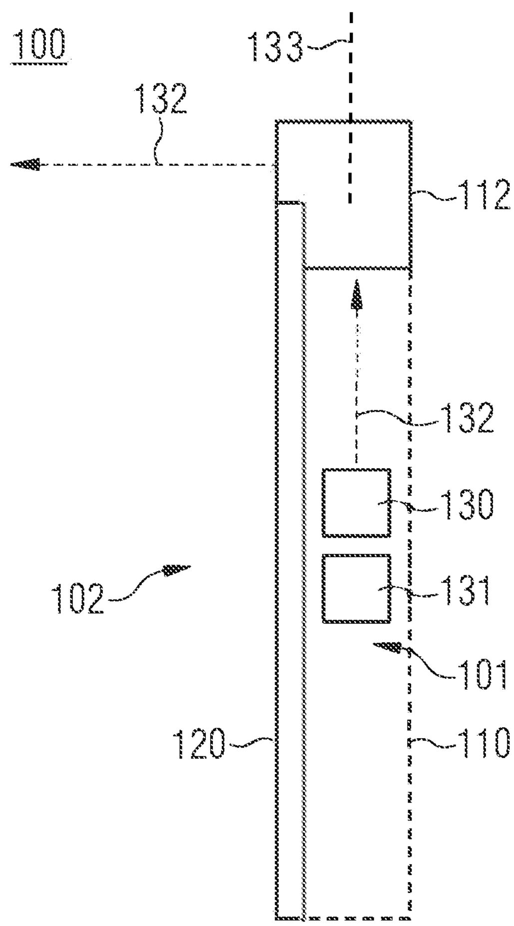


FIG. 2a

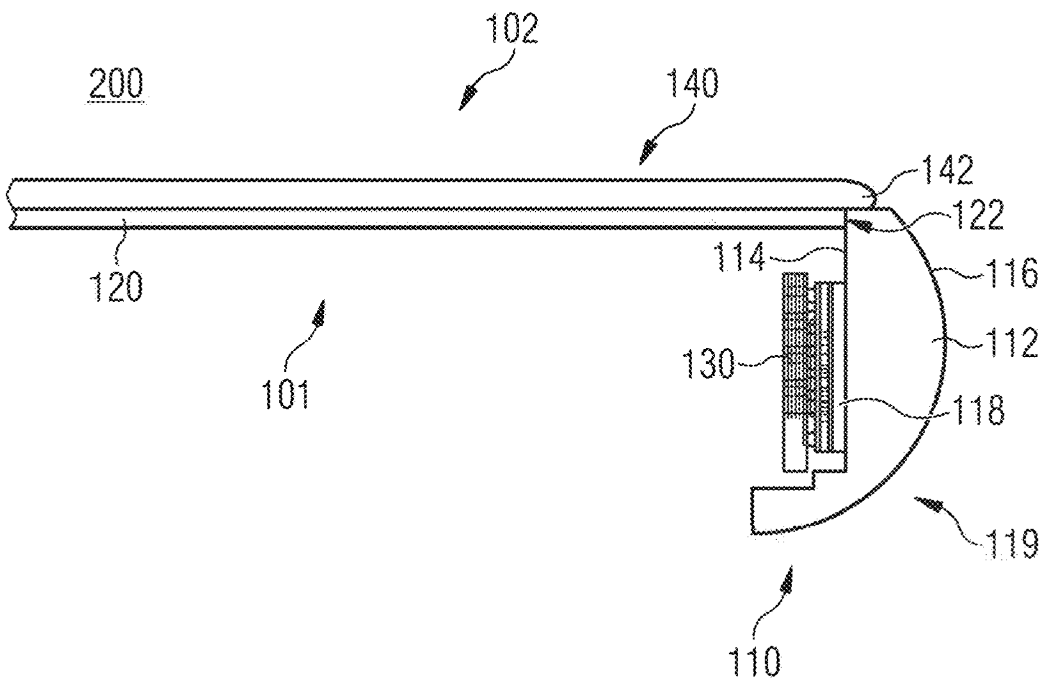

102
200
140
142
122
120
114
116
112
130
118
101
119
110

FIG. 2b

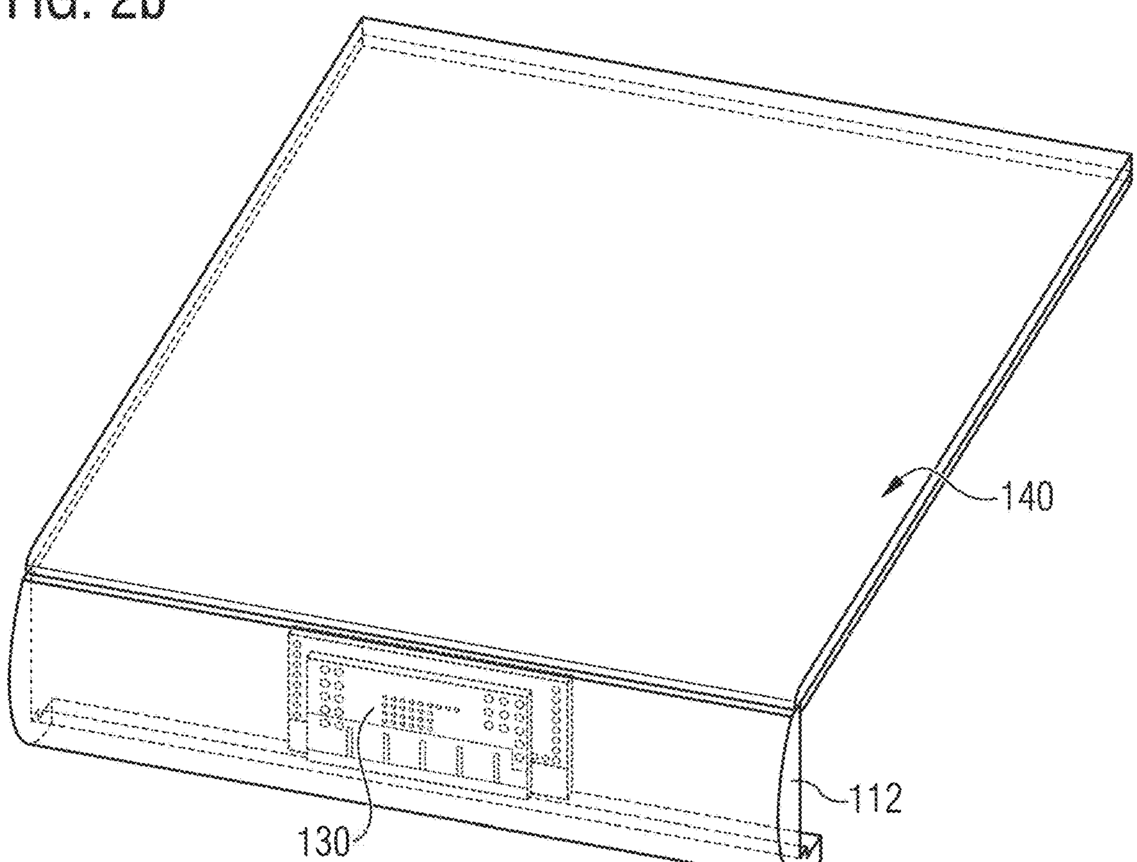

140
112
130

FIG. 3a

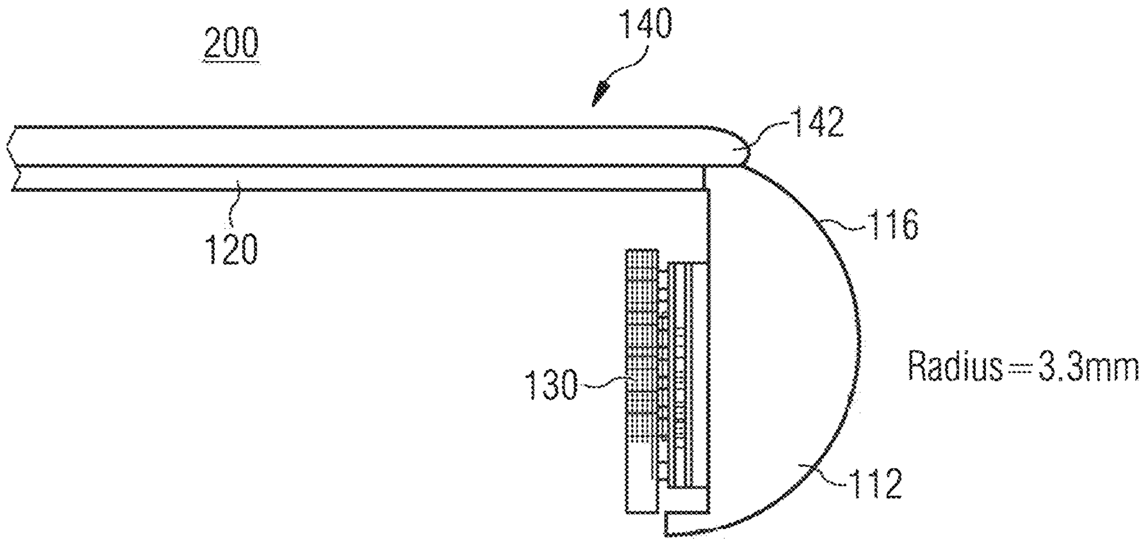

200
140
142
116
120
130
Radius=3.3mm
112

FIG. 3b

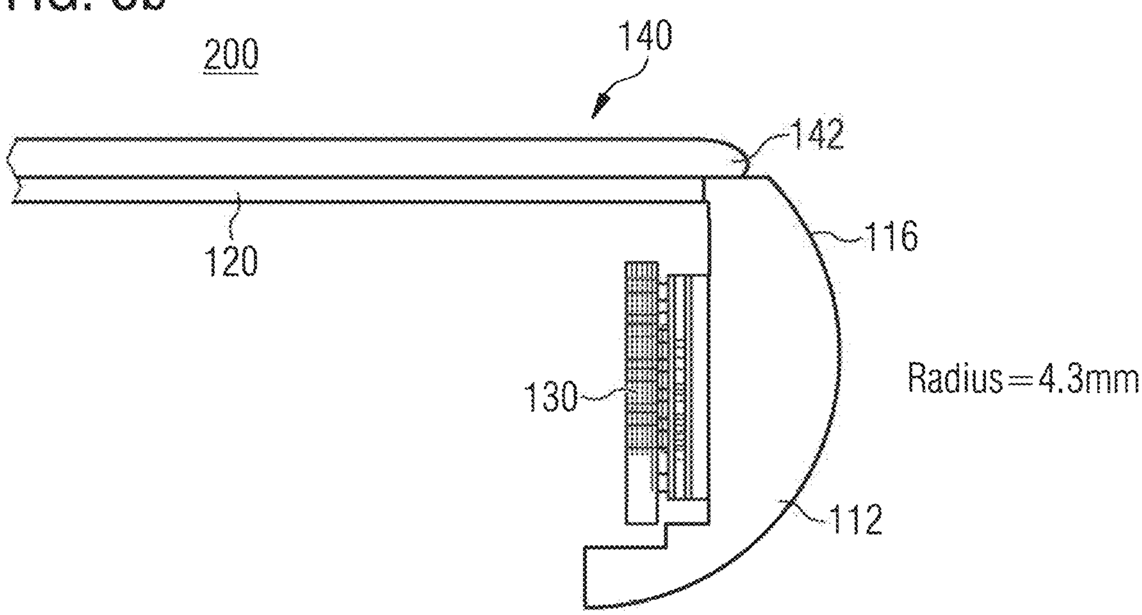

200
140
142
116
120
130
Radius=4.3mm
112

FIG. 3c

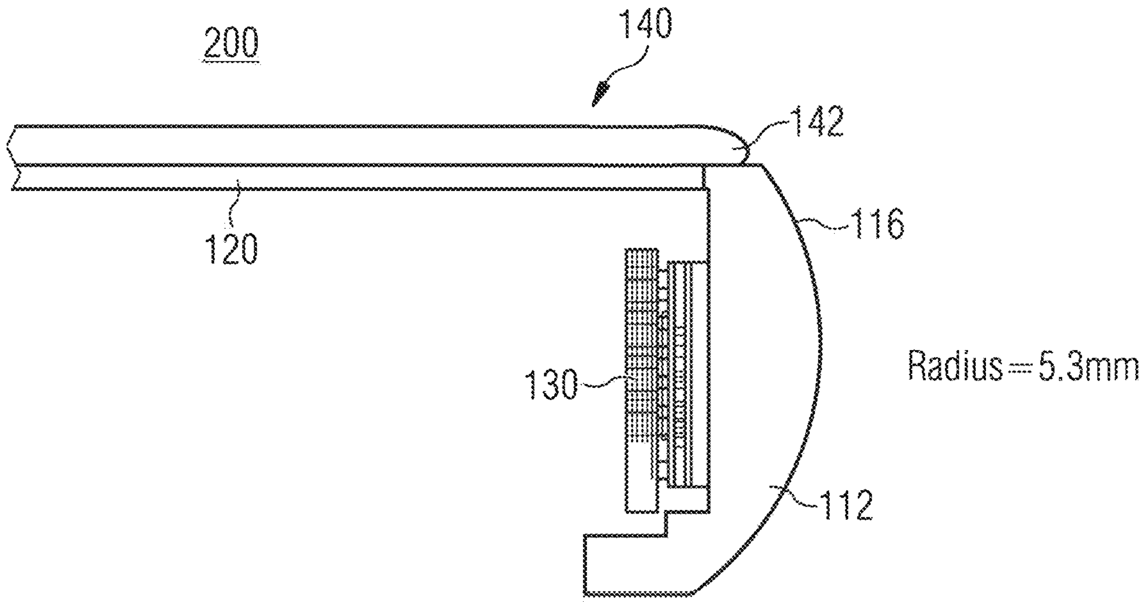

200
140
142
116
120
Radius=5.3mm
130
112

FIG. 3d

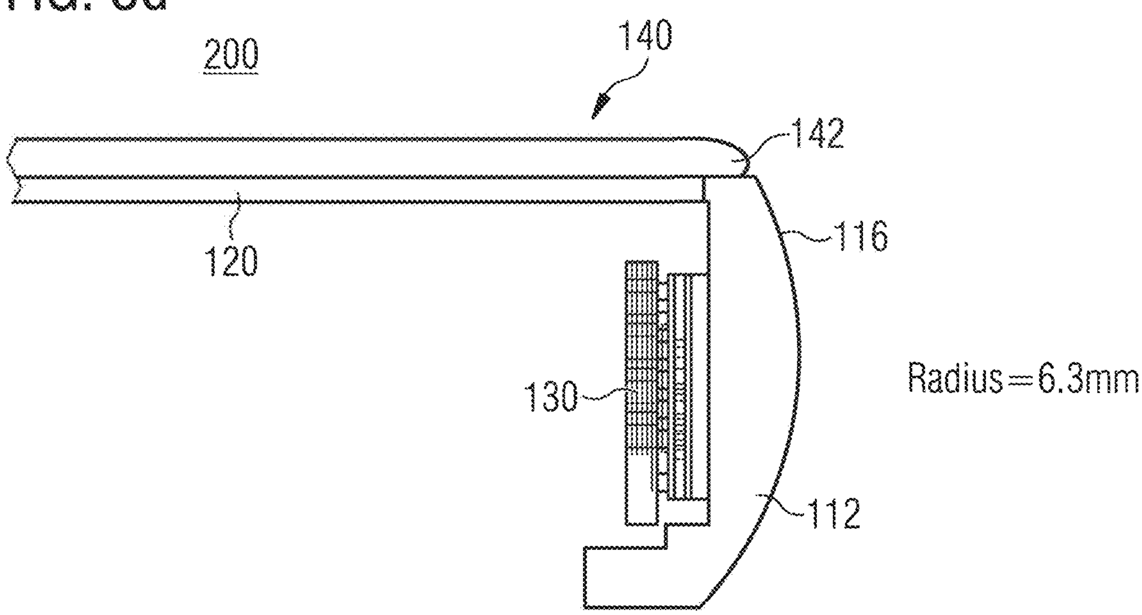
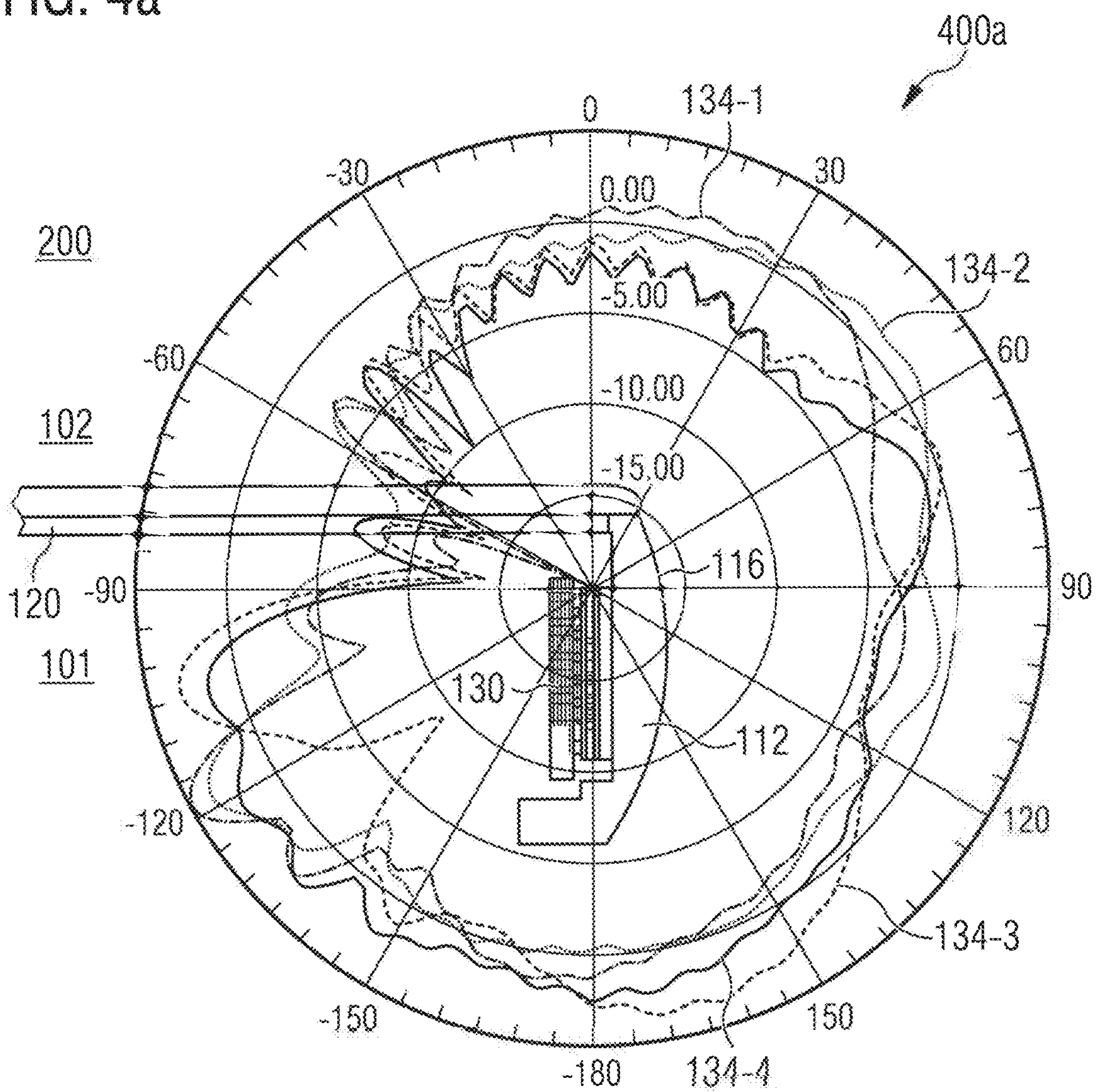
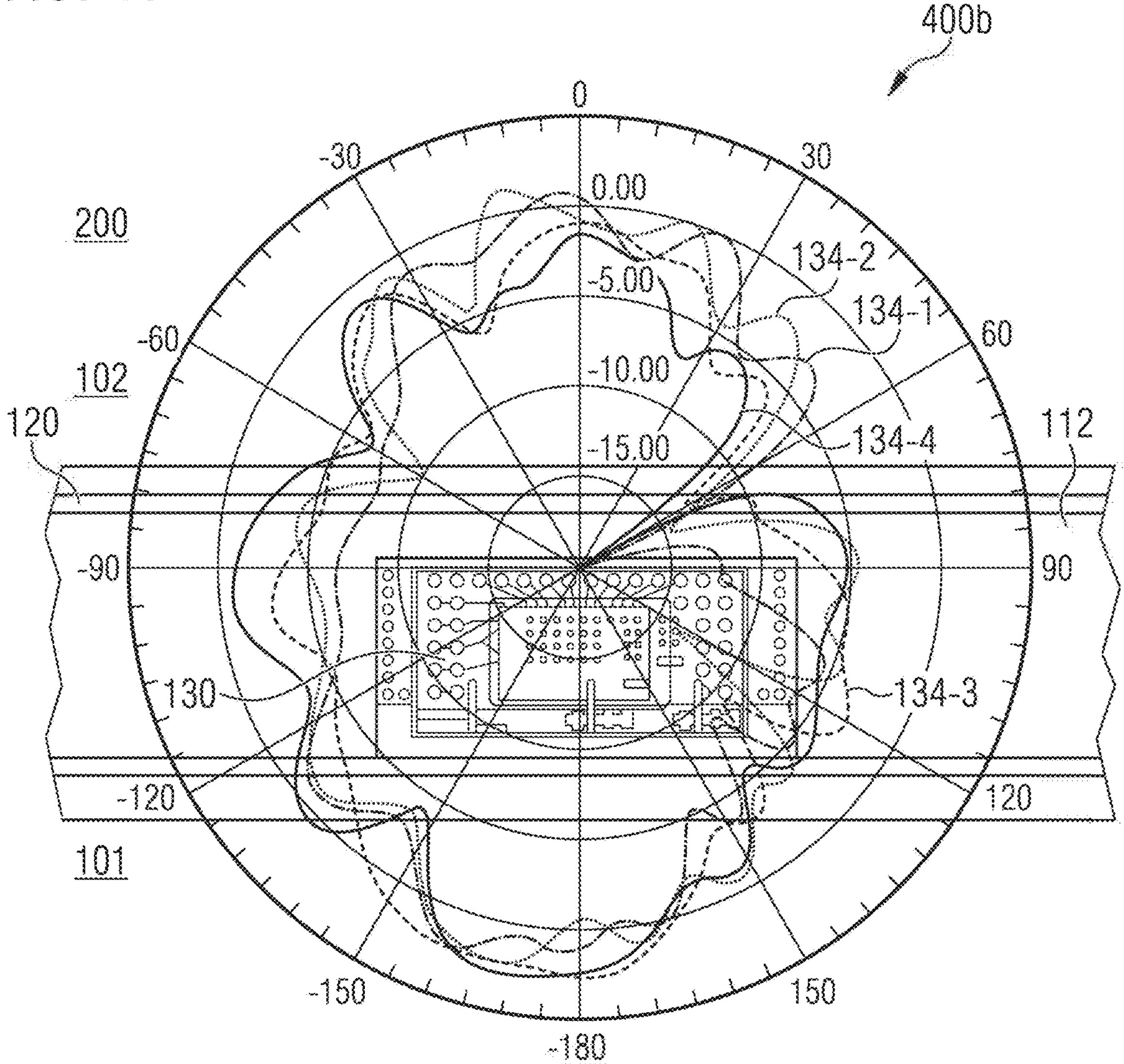

200
140
142
116
120
Radius=6.3mm
130
112

FIG. 4a



400a
0
134-1
-30
30
0.00
200
134-2
-5.00
-60
60
-10.00
102
-15.00
116
120
-90
90
101
130
112
-120
120
134-3
-150
150
-180
134-4

FIG. 4b



400b
0
30
60
90
120
150
-180
-150
-120
-90
-60
-30
0.00
-5.00
-10.00
-15.00
134-2
134-1
134-4
134-3
200
102
120
112
130
101

FIG. 5a

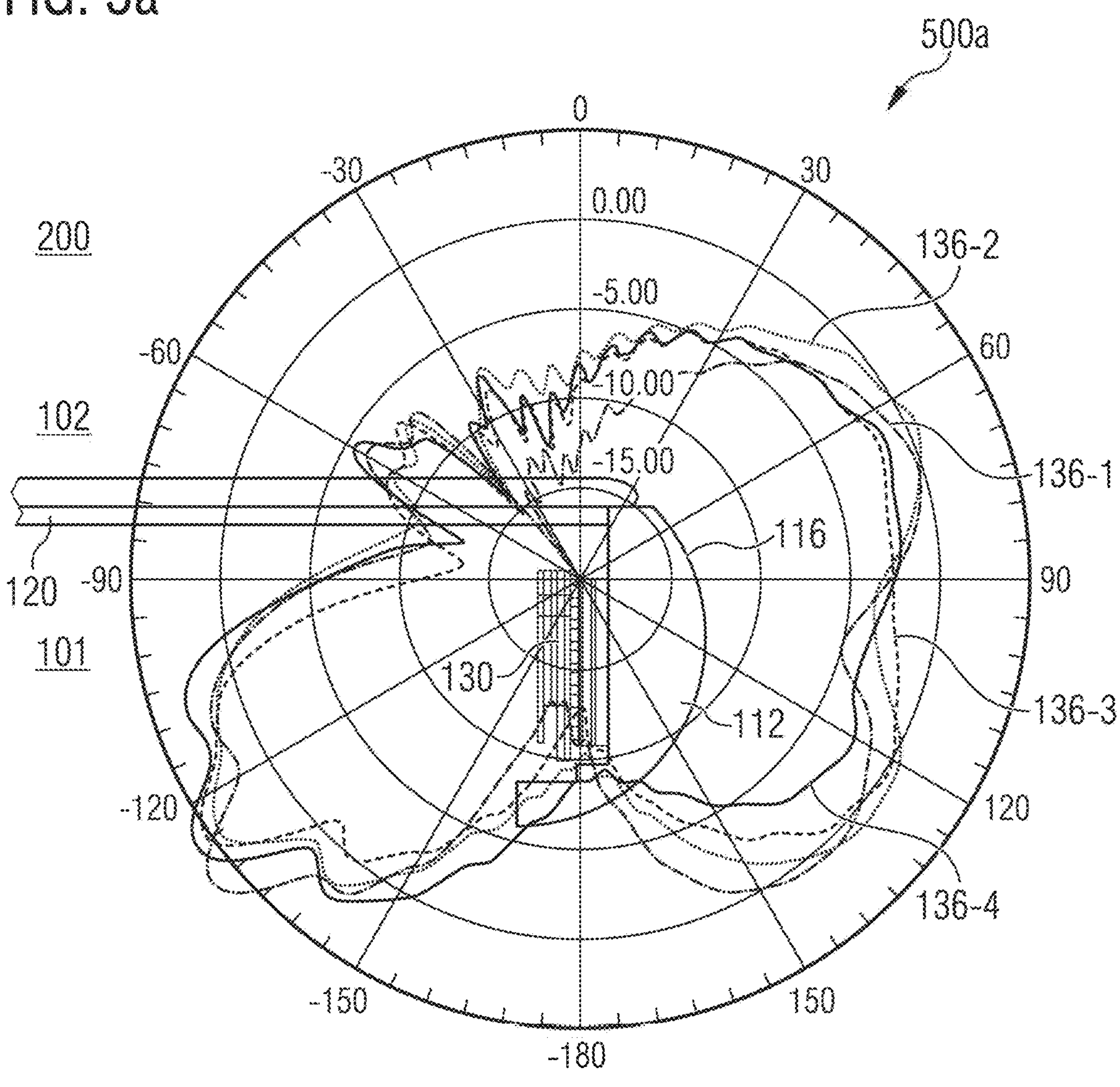
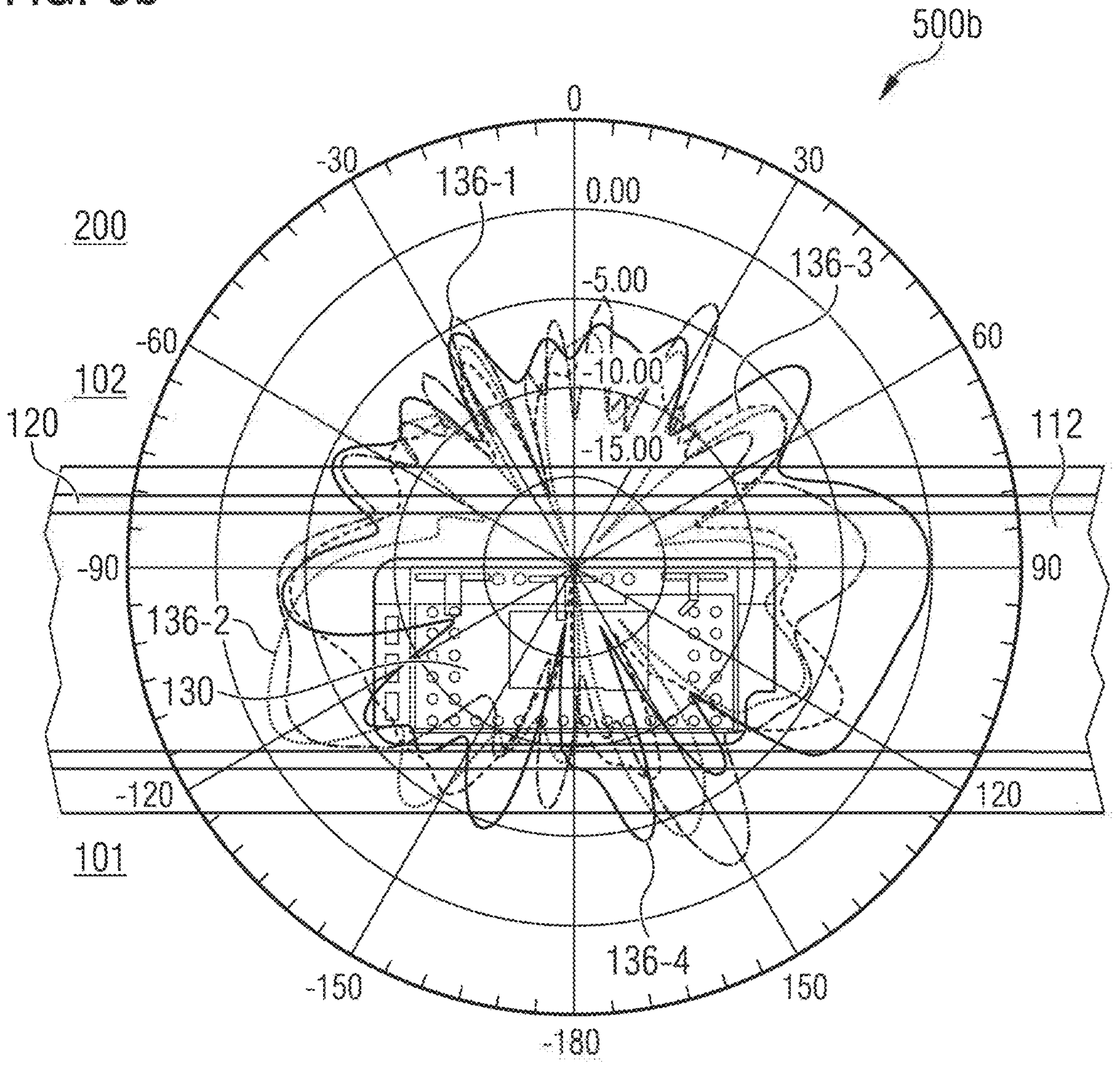
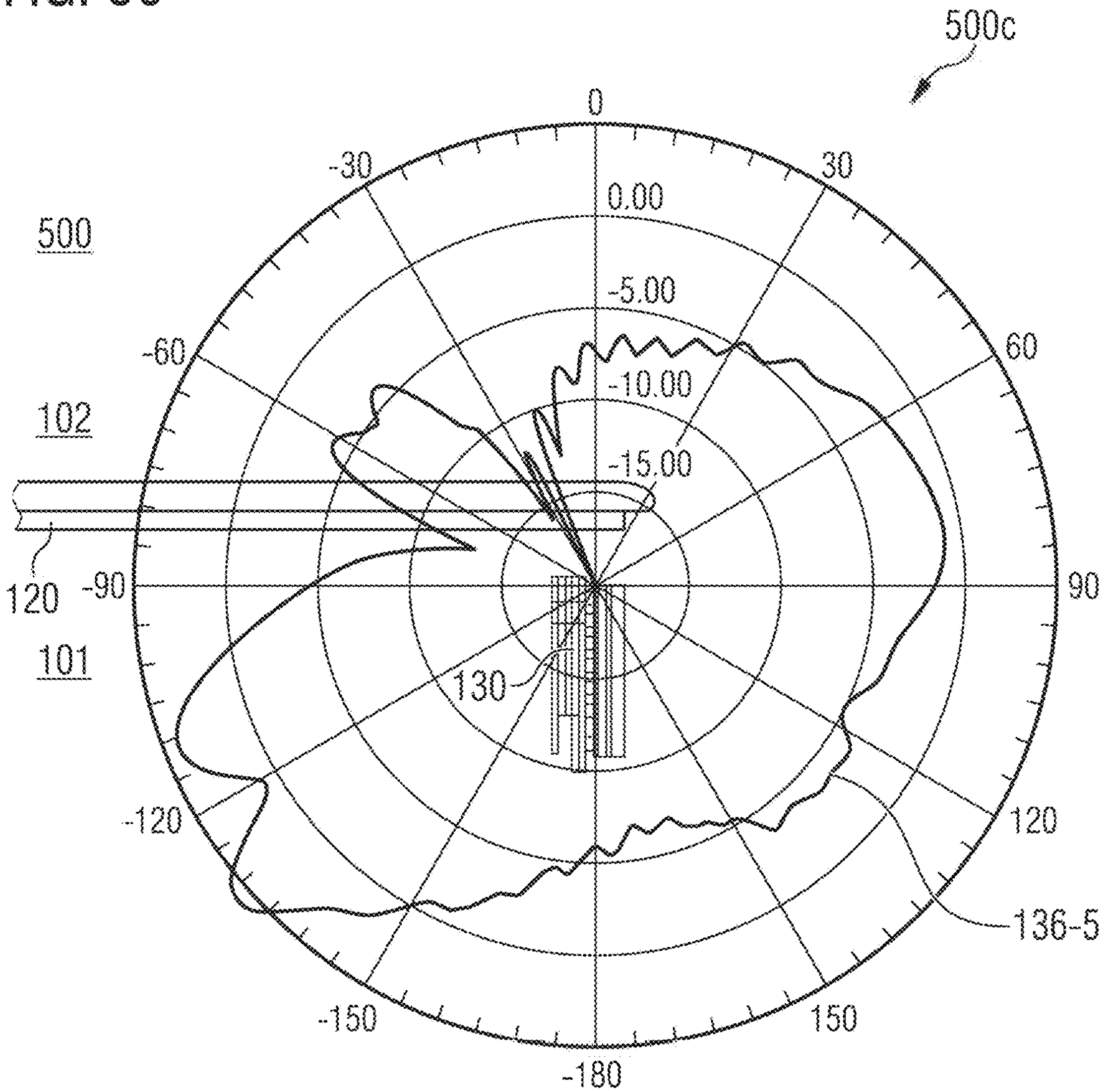

500a
0
-30
30
0.00
200
136-2
-5.00
-60
60
-10.00
102
136-1
-15.00
116
120
-90
90
101
130
136-3
112
-120
120
136-4
-150
150
-180

FIG. 5b



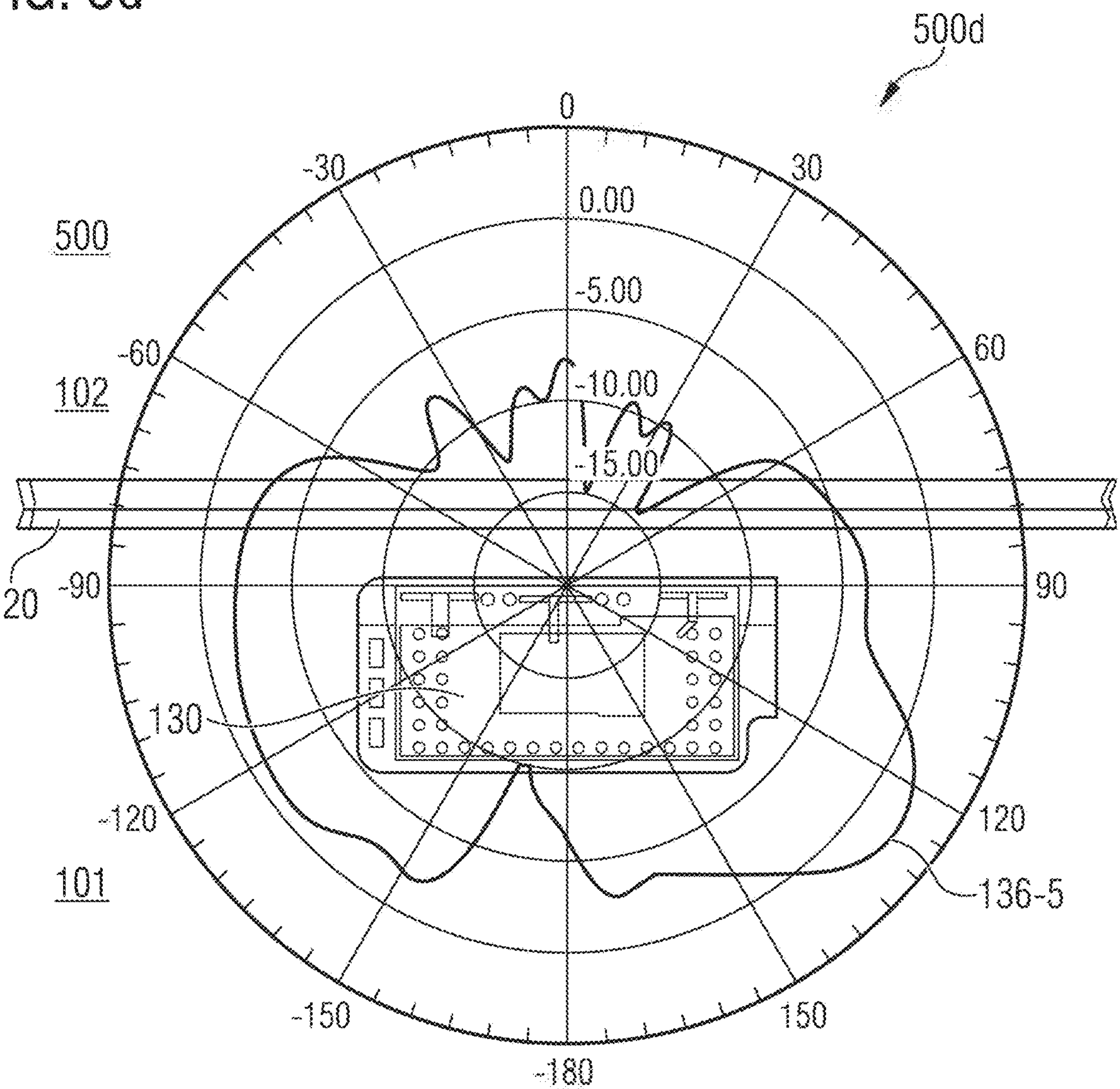
500b
0
-30
30
136-1
0.00
200
-5.00
136-3
-60
60
-10.00
102
120
-15.00
112
-90
90
136-2
130
-120
120
101
136-4
-150
150
-180

FIG. 5c



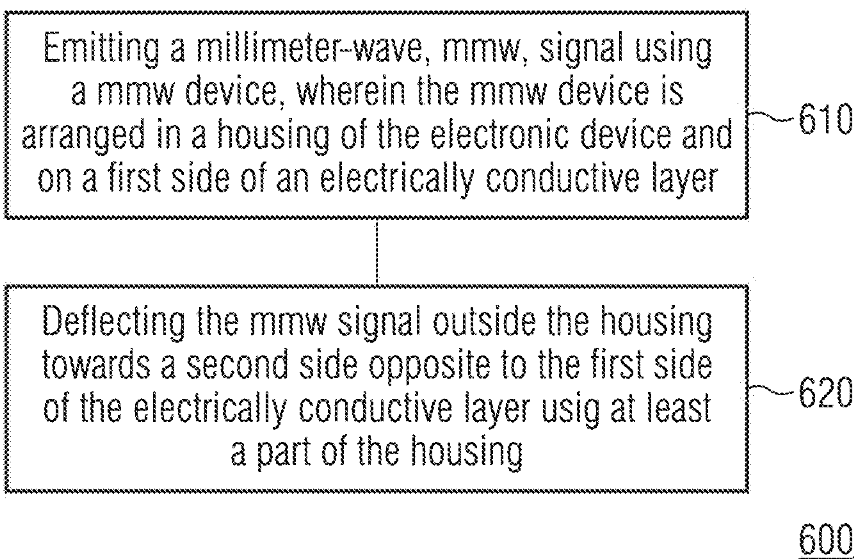
500c
0
-30
30
0.00
500
-5.00
-60
60
-10.00
102
-15.00
120
-90
90
101
130
-120
120
136-5
-150
150
-180

FIG. 5d



500d
0
-30
30
0.00
500
-5.00
-60
60
-10.00
102
-15.00
120
-90
90
130
-120
120
101
136-5
-150
150
-180

FIG. 6


Emitting a millimeter-wave, mmw, signal using a mmw device, wherein the mmw device is arranged in a housing of the electronic device and on a first side of an electrically conductive layer
610
Deflecting the mmw signal outside the housing towards a second side opposite to the first side of the electrically conductive layer usig at least a part of the housing
620
600

MILLIMETER-WAVE CIRCUIT WITH DIELECTRIC LENS

This application claims the benefit of European Patent Application No. 20194867, filed on Sep. 7, 2020, which application is hereby incorporated herein by reference in its entirety.

TECHNICAL FIELD

Embodiments of the present disclosure relate to a millimeter wave circuit with a dielectric lens.

BACKGROUND

Millimeter-wave circuitries (e.g. radar circuits) play an important role in electronic devices, for example, for gesture sensing/detection or movement detection purposes.

Radar circuitries, for example, are implemented in smartphones or tablets for gesture sensing and other use cases. In smartphones with "bezel less" touch displays, radar circuitry can merely be placed behind a touch-sensitive metal layer of the touch display. Due to its electrical properties, the metal layer may block a radar signal of the radar circuitry. Therefore, a radiation pattern of the radar signal may be insufficient, for example, for environment, object, movement, and/or gesture sensing.

SUMMARY

Some examples relate to an electronic device. The electronic device comprises a housing and an electrically conductive layer. Further, the electronic device comprises a millimeter-wave (mmw) circuitry configured to emit a mmw signal. The mmw circuitry is arranged in the housing and on a first side of the electrically conductive layer. The housing comprises at least one portion configured as a dielectric lens to refract the mmw signal at least partially outside the housing towards a second side opposite to the first side of the electrically conductive layer.

Some examples relate to a method for an electronic device which comprises a housing and an electrically conductive layer. The method comprises emitting a mmw signal using a mmw circuitry arranged in the housing and on a first side of the electrically conductive layer. Further, the method comprises refracting at least a part of the mmw signal outside the housing towards a second side opposite to the first side of the electrically conductive layer using a portion of the housing, the portion being configured as a dielectric lens.

BRIEF DESCRIPTION OF THE DRAWINGS

Some examples of apparatuses and/or methods will be described in the following by way of example only, and with reference to the accompanying figures, in which:

FIG. **1** schematically illustrates a cross-section of a first example of an electronic device equipped with millimeter-wave circuitry;

FIGS. **2***a* and **2***b* illustrate a cross-section and an oblique view of a second example of an electronic device;

FIGS. **3***a*, **3***b*, **3***c*, and **3***d* illustrate various examples of dielectric lenses having different radii;

FIGS. **4***a* and **4***b* illustrate various exemplary radiation patterns from a top view and a side view;

FIGS. **5***a*, **5***b*, **5***c*, and **5***d* illustrate various other radiation patterns from a top view and a side view; and

FIG. **6** illustrates a method for an electronic device.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

Some examples are now described in more detail with reference to the enclosed figures. However, other possible examples are not limited to the features of these embodiments described in detail. Other examples may include modifications of the features as well as equivalents and alternatives to the features. Furthermore, the terminology used herein to describe certain examples should not be restrictive of further possible examples.

Throughout the description of the figures same or similar reference numerals refer to same or similar elements and/or features, which may be identical or implemented in a modified form while providing the same or a similar function. The thickness of lines, layers and/or areas in the figures may also be exaggerated for clarification.

When two elements A and B are combined using an 'or', this is to be understood as disclosing all possible combinations, i.e. only A, only B as well as A and B, unless expressly defined otherwise in the individual case. As an alternative wording for the same combinations, "at least one of A and B" or "A and/or B" may be used. This applies equivalently to combinations of more than two elements.

If a singular form, such as "a", "an" and "the" is used and the use of only a single element is not defined as mandatory either explicitly or implicitly, further examples may also use several elements to implement the same function. If a function is described below as implemented using multiple elements, further examples may implement the same function using a single element or a single processing entity. It is further understood that the terms "include", "including", "comprise" and/or "comprising", when used, describe the presence of the specified features, integers, steps, operations, processes, elements, components and/or a group thereof, but do not exclude the presence or addition of one or more other features, integers, steps, operations, processes, elements, components and/or a group thereof.

Some embodiments of the present disclosure relate to beam shaping of millimeter-wave radiation in electronic devices and a method for beam shaping.

FIG. **1** schematically illustrates a cross-section of an electronic device **100**. The electronic device **100** comprises a housing **110**, an electrically conductive layer **120**, and a millimeter-wave, mmw, circuitry **130** configured to emit a mmw signal **132**. In context of the present disclosure, the mmw circuitry **130** particularly may refer to a mmw device comprising a signal generation/processing circuitry, as well as one or more antennas to emit the mmw signal **132**. The mmw circuitry **130** is arranged in the housing **110** and on a first side **101** of the electrically conductive layer **120**. The housing **110** comprises a portion configured as a dielectric lens **112** to refract the mmw signal **132** at least partially outside the housing **110** towards a second side **102** opposite to the first side **101** of the electrically conductive layer **120**. In other words, at least a part of the housing forms the dielectric lens **112**, whose presence causes the radiation pattern of the mmw signal **132** to be enhanced at the second side of the electrically conductive layer **120**. In FIG. **1**, e.g., a (half-) space to the right of the electrically conductive layer **120** is to be understood as the first side **101** and a (half-) space to the left is to be understood as the second side **102**.

The mmw circuitry **130**, e.g., comprises signal generation circuitry (not shown) for generating the mmw signal **132** and transmit circuitry or a transmit antenna (not shown) to emit the mmw signal **132**. In context of the present disclosure, the mmw signal **132** is to be understood as electromagnetic signal. In particular, the mmw signal **132** may have a frequency between 30 GHz and 300 GHz which, e.g., can be used for radar sensing. Accordingly, the mmw circuitry **130** may be configured as radar circuitry, e.g., for characterizing the environment of the electronic device **100** using the mmw signal **132**.

The electrically conductive layer **120**, for example, is part of a touchscreen, the housing **110**, or another component of the electronic device **100**. In the example of FIG. **1**, the electrically conductive layer **120** is attached to the housing **110**. In other examples, the electrically conductive layer **120** can be arranged differently in the electronic device **100**. Due to its electrical characteristics, the electrically conductive layer **120** may block at least a portion of the mmw signal **132** emitted towards the second side **102**.

In the example of FIG. **1**, the housing **110** comprises a portion forming the dielectric lens **112**. In the example of FIG. **1**, the housing **110** comprises one dielectric lens. In particular, the dielectric lens **112** is formed by all or part of an edge portion of the housing **110**. The edge portion, for example, is a part of a frame of the housing **110**. For example, the dielectric lens **112** extends over a part of a length (e.g. a length of one side) of the frame. In other examples, the housing can also exhibit multiple dielectric lenses, e.g., to increase a portion of the mmw signal **132** refracted towards the second side **102**.

The dielectric lens **112** may at least partially consist of dielectric/electrically insulating material transparent to the mmw signal **132**. The dielectric material, e.g., is plastic. It is noted that also other dielectric/electrically insulating materials may constitute the dielectric lens **112**. Optionally, one dielectric material or a composition of various different dielectric materials of the housing **110** may constitute the dielectric lens **112**. For example, multiple stacked layers of different dielectric materials may form the dielectric lens **112**. Further, the dielectric **112** lens may exhibit one or more phase transitions between the dielectric materials and/or an adjacent material or medium (e.g. air) to refract the mmw signal **132** at the phase transition. This particularly allows beam shaping of the mmw signal **132** for a modification of a radiation pattern of the mmw signal **132**. In this regard, the dielectric lens **112** e.g. is configured to refract the mmw signal **132** impinging the dielectric lens **112** at least partially towards the second side **102**. This allows the dielectric lens **112**, e.g., to deflect the mmw signal **132** "around" the electrically conductive layer **120** towards the second side **102**. In this way, the radiation pattern of the mmw signal **132** may be modified or enhanced to provide an increased and/or sufficient amount of the mmw signal **132** to the second side **102** for, e.g. object or gesture sensing.

The skilled person will understand that radiation beams propagating (exactly) in reverse direction through the dielectric lens **112** may follow the same path. Therefore, the dielectric lens **112** may be also configured to at least partly refract reflections of the mmw signal **132** from the second side **102** towards the mmw circuitry **130**. The mmw circuitry **130** further may be configured to receive the reflections. The mmw circuitry **130**, e.g., comprises one or more receive antennas (not shown) configured to receive the reflections. The reflections may be indicative of positions and/or velocities of objects on the second side **102** of the electrically conductive layer **120**. Thus, the reflections of the mmw signal **132** may enable detection of objects, movements, and/or gestures on the second side **102** based on those reflections. To this end, the electronic device **100** my further comprise data processing circuitry **131** configured to detect movements of a user on the second side of the electrically conductive layer using the reflections. The data processing circuitry **131**, e.g., can compare the mmw signal **132** and the reflections to determine a time of flight and/or a frequency shift of the reflections compared to the mmw signal **132** and to deter-mine the user's movements from the time of flight and/or the frequency shift.

The electronic device **100**, for example, is a mobile device, a household electronics device, or an entertainment electronics device. In particular, the electronic device **100** can be a phone, a tablet, a television (TV), or the like.

FIGS. **2***a* and **2***b* illustrate a cross-section and an oblique view of another electronic device **200**. In comparison to the electronic device **100**, the electronic device **200** further comprises a touchscreen **140** comprising a display **142**. In the electronic device **200**, the electrically conductive layer **120** forms a part of the touchscreen **140** for sensing touches. In particular, the electrically conductive layer **120** can be a metallic coating of the display **142**. The electrically conductive layer **120**, e.g., is used to generate an electrical field and sense disturbance of the electric field when the user touches the display **142**. This allows touches of the user on the display **142** to be sensed based on the disturbance of the electrical field. The display **142**, e.g., is arranged on the second side **102** of the electrically conductive layer **120**. It is noted that the touchscreen may exhibit different architectures, e.g., in which the electrically conductive layer **120** and/or the display **142** are arranged and/or formed differently.

As can be seen in FIG. **2***a*, the dielectric lens **112** can be formed in an outer portion, e.g., in a frame **119** of the housing **110**. The frame **119**, e.g., surrounds an outer edge **122** of the electrically conductive layer **120**. In other words, the electrically conductive layer **120** is framed in the housing **110**. Also, the housing **110** may be attached to the display **142**, e.g., closing the housing towards the second side **102**. In other example, the (entire) touchscreen is framed in the housing **110** to firmly fix the touchscreen in the electronic device **200**.

As can be seen from FIG. **2***a*, the dielectric lens **112** is partially arranged on the first side **101** of the electrically conductive layer **120** in order to intersect at least a portion of the mmw signal **132** emitted by the mmw circuitry **130** on the first side **101**. In some examples, the dielectric lens is entirely arranged on the first side **101**. Further, the dielectric lens **112** protrudes at least partially over the edge **122** of the electrically conductive layer **120** to deflect the mmw signal **132** around the electrically conductive layer **120**. In the electronic device **200**, e.g., the entire dielectric lens **112** protrudes over the edge **122**. However, in other examples, merely a part of the dielectric lens **112**, e.g., an exterior refractive surface forming an outer phase transition of the dielectric lens **112** partially protrudes over the edge **122**.

The skilled person will understand that properties (e.g. lens type, refractive index, transparency, material composition) of the dielectric lens **112**, a positioning (e.g. position or orientation) of the dielectric lens **112** and the mmw circuitry **130** with respect to each other and the electrically conductive layer **120**, and an emission characteristic of the mmw circuitry **130** have influence on the radiation pattern of the mmw signal **132**. In context of the present disclosure, the emission characteristic can be understood as an "unmodified" radiation pattern of a stand-alone application of the mmw circuitry **130**. It is to be noted that various examples of the proposed architecture may exhibit, different lenses with different properties, different positionings of the dielectric lens **112** and the mmw circuitry **130**, and/or different mmw circuitries **130** having different emission characteristics.

In the following some different architectures are exemplarily described.

The dielectric lens **112** can exhibit various different lens types. Exemplary lens types are simple lenses, such as convex or concave lenses, and compound lenses which comprise a combination of simple lenses. In the electronic device **200**, the dielectric lens **112** may be a simple lens. The dielectric lens **112** e.g., is configured as a convex lens. Examples of convex lenses are plano-convex lenses having a planar face and a convex surface on opposite sides of the convex lens or biconvex lenses having oppositely formed convex surfaces on opposite sides of the convex lens. In the electronic device **200**, e.g., the dielectric lens **112** is configured as a plano-convex lens having a planar face **114** and a convex surface **116** opposite to the planar face **114**. The planar face **114** is turned towards the inside of the housing **110**, whereas the convex surface **116** is turned outwards. Hence, the convex sur-face **116** can be understood as a refractive exterior surface.

It is noted that the dielectric lens **112** alternatively can exhibit another lens type, e.g., to provide a different radiation pattern. The dielectric lens **112**, e.g., may be biconvex or a compound lens comprising a combination of a convex and a concave lens, e.g., exhibiting different or same dielectric materials.

Also, the positioning of the dielectric lens **112** and the mmw circuitry **130** may have an influence on the radiation pattern. In exemplary positionings, the mmw circuitry **130** may be either placed distant from the dielectric lens **112**, as can be seen in FIG. **1**, or may be attached adjacent to the dielectric lens **112**, as shown in FIG. **2***a*. The skilled person will understand that the closer the mmw circuitry **130** is placed to the dielectric lens **112**, the greater may be the portion of the mmw signal **132** impinging the dielectric lens **112** and thus, the greater may be the portion of the mmw signal **132** refracted towards the second side **102**. Therefore, an increasing portion of the mmw signal **132** may be refracted towards the second side **102** the closer the mmw circuitry **130** is placed to the dielectric lens **112**. In particular, this may enable a more precise and more reliable sensing of the environment, objects, movements, and/or gestures. In the electronic device **200**, the mmw circuitry **130**, e.g., is attached (adjacent) to the planar face **114** to increase a portion of the mmw signal **132** refracted towards the second side **102** vis-à-vis to other architectures, e.g., illustrated in FIG. **1**.

In order to attach the transmit circuitry **130** to the dielectric lens **112**, e.g., an adhesive **118** can be used. The adhesive **118** may be at least partly transmissive for the mmw signal **132** to direct the mmw signal **132** through the adhesive **118**. The skilled person is aware that the higher the permeability of the adhesive for the mmw signal **132**, the more intense may be the mmw signal **132** impinging the dielectric lens **112** and the more intense may be the mmw signal **132** on the second side **102**. Alternatively, other means (e.g. clamps or screw connections) may be used to attach the mmw circuitry **130** to the dielectric lens **112**. The mmw circuitry **130** may be also planar. Thus, it may be technically easier to attach the mmw circuitry **130** to the planar face **114** than to a curved face, e.g., of a biconvex lens.

It is noted that the mmw circuitry **130** can exhibit also different lateral displacements or orientations with respect to the dielectric lens **112** to, for example, effectuate different radiation patterns in some applications.

Also, the dielectric lens **112** can exhibit different orientations (with respect to the mmw circuitry **130**). In particular, the orientation may be represented by an orientation of an optical axis **133** of the dielectric lens **112**. The optical axis **133** is, e.g., to be understood as symmetry axis of the dielectric lens **112**. In the electronic device **200**, the plano-convex dielectric lens **112** is arranged such that the planar surface **114** is perpendicular to the electrically conductive layer **120**. Thus, an optical axis **133** of the dielectric lens **112** may be parallel to the electrically conductive layer **120**. As can be seen from FIG. **2***a*, the above proposed orientation of the dielectric lens **112** may particularly allow a more space-saving implementation of the dielectric lens **112** as if the dielectric lens **112** was inclined differently relative to the electrically conductive layer **120**.

The radiation pattern may also depend on a shape of the dielectric lens **112**. In the electronic device **200**, the radiation pattern may particularly depend on a radius or curvature of the convex surface **116**. The exterior refractive surface/convex surface **116**, e.g., has a radius between 3 mm and 7 mm. Dielectric lenses with such radii may be easily implemented in frames of existing smartphone or tablet housings. It is noted that, in other examples, the exterior refractive surface may also exhibit another radius less than 3 mm or greater than 7 mm. The skilled person will understand that also for other lens types (e.g. biconvex lens), the dielectric lens **112** may exhibit different shapes. In general, the dielectric lens **112** may also exhibit a different, e.g., an elliptical or an asymmetric or shape.

FIG. **3***a*, FIG. **3***b*, FIG. **3***c*, and FIG. **3***d* each illustrate a cross-section of the electronic device **200**, whereas the dielectric lens **112** has different radii in FIG. **3***a*, . . . , and FIG. **3***d*.

In the example of FIG. **3***a*, the convex surface **116** of the dielectric lens **112** has a radius of 3.3 mm. In FIG. **3***b*, the convex surface **116** has a radius of 4.3 mm. As can be seen in FIG. **3***c*, the convex surface **116** may also exhibit a radius of 5.3 mm. In the example of FIG. **3***d*, the convex surface **116** of the dielectric lens **112** has a radius of 6.3 mm. The skilled person will understand that the radiation pattern of the mmw signal **132** may be different for the different radii of the dielectric lens **112**, as illustrated with reference to FIGS. **4***a* and **4***b* in more detail.

FIGS. **4***a* and **4***b* illustrate various exemplary radiation patterns **134-1**, **134-2**, **134-3**, and **134-4** of the mmw signal **132** for the different radii of the dielectric lens from a top view and a side view.

FIG. **4***a* shows a polar diagram **400***a*, whereas an angle of the polar diagram **400***a* denotes a radiation angle in a vertical plane of the mmw circuitry **130** with respect to a perpendicular to the electrically conductive layer **120**, and a distance from a point of origin of the polar diagram **400***a* denotes an intensity of the mmw signal **132** in a respective radiation angle. The point of origin, e.g., is a point on the mmw circuitry **130**.

The radiation patterns **134-1**, **134-2**, **134-3**, and **134-4**, e.g., relate to different radii for the convex surface **116** of the dielectric lens **112**. For example, 134-1 relates to the radius of 3.3 mm, **134-2** to the radius of 4.3 mm, **134-3** to the radius of 5.3 mm, and **134-4** to the radius of 6.3 mm.

In diagram **400***a*, a portion of the radiation pattern between an angle of −90° and 90° indicates an amount of the mmw signal **132** on the second side, whereas another portion of the radiation pattern for angles of more than 90° or less than −90° indicates an amount of the mmw signal **132** on the first side of the electrically conductive layer **120**.

As can be seen from the polar diagram **400***a*, the different radiation patterns **134-1**, **134-2**, **134-3**, and **134-4** may exhibit different intensities with respect to each other for different radiation angles. Radiation pattern **134-1**, e.g., has the highest intensity among the **134-1**, **134-2**, **134-3**, and **134-4** at a radiation angle of 0° in the vertical plane. Thus, the radius of 3.3 mm for the convex surface **116** may be preferred over the larger radii 4.3 mm, 5.3 mm, and 6.3 mm to provide a maximal intensity at a radiation angle of 0° using one of the aforementioned radii. Depending on requirements on the radiation pattern in different applications, either one of the above radii may be used. Alternatively, a different radius may be used.

FIG. **4***b* shows the radiation patterns **134-1**, **134-2**, **134-3**, and **134-4** for different radii of the convex surface **116** from top view and in a horizontal plane of the mmw circuitry **130**. In particular, the radiation patterns **134-1**, **134-2**, **134-3**, and **134-4** are plotted in the polar diagram **400***b*, whereas an angle of the polar diagram **400***b* denotes a radiation angle with respect to a perpendicular to the electrically conductive layer **120**. A distance from a point of origin of the polar diagram **400***a* denotes an intensity of the mmw signal **132** in a respective radiation angle.

Again, a portion of the radiation pattern between an angle of −90° and 90° indicates an amount of the mmw signal **132** on the second side, whereas another portion of the radiation pattern for angles of more than 90° or less than −90° indicates an amount of the mmw signal **132** on the first side of the electrically conductive layer **120**.

Again, the different radiation patterns **134-1**, **134-2**, **134-3**, and **134-4** at least partly differ from each other. Radiation pattern **134-1**, e.g., has the highest intensity among the **134-1**, **134-2**, **134-3**, and **134-4** at a radiation angle of 0° in the horizontal plane. Therefore, the radiation pattern **134-1** may be preferred over **134-2**, **134-3**, and **134-4** in some applications. In other applications, different radiation pattern and thus, different radii may be preferred.

The radiation pattern of the mmw signal **132** may also depend on the emission characteristic of the mmw circuitry **130**. The emission characteristic particularly may depend on an antenna (e.g. antenna type) used in the mmw circuitry **130** to emit the mmw signal **132**. In the example of FIGS. **4***a* and **4***b*, e.g., the mmw circuitry **130** comprises a slot-antenna to emit the mmw signal **132**. It is noted that other antenna types may be used as well in other examples. For example, the mmw circuitry **130** may comprise a Yagi antenna to emit the mmw signal **132**.

FIG. **5***a* and FIG. **5***b* illustrate various exemplary radiation patterns **136-1**, **136-2**, **136-3**, and **136-4** of the mmw signal **132** emitted by a Yagi antenna. Again, the radiation pattern **136-1**, **136-2**, **136-3**, and **136-4** relate to different radii of the dielectric lens **112**. FIG. **5***a*, for example, illustrates the radiation patterns **136-1**, **136-2**, **136-3**, and **136-4** plotted in a polar diagram **500***a* equivalent to the polar diagram **400***a*, and FIG. **5***b* illustrates the radiation patterns **136-1**, **136-2**, **136-3**, and **136-4** plotted in a polar diagram **500***b* equivalent to the polar diagram **400***b*. Also, the radiation patterns **136-1**, **136-2**, **136-3**, and **136-4** differ from each other for different radii of the convex surface **116**. Moreover, the radiation patterns **136-1**, **136-2**, **136-3**, and **136-4** at least partially differ from the radiation patterns **134-1**, **134-2**, **134-3**, and **134-4**. In different examples, the mmw circuitry **130** may there-fore comprise different antennas and/or the dielectric lens **112** may exhibit different radii.

As previously explained, the dielectric lens **112** may enhance the radiation pattern, e.g., to provide a sufficient intensity of the mmw signal **132** on the second side **102** for sensing the environment, objects, movements, and/or gestures. This can be exemplarily illustrated with reference to a comparison between FIG. **5***a* and FIG. **5***c* and between FIGS. **5***b* and **5***d*.

FIG. **5***c* and FIG. **5***d* illustrate a radiation pattern **136-5** of an electronic device **500** in the vertical plane and in the horizontal plane, respectively, in a polar diagram **500***c* and **500***d* equivalent to the polar diagrams **500***a* and **500***b*, respectively. For reasons of comparability, the electronic device **500** may also exhibit a similar touchscreen **140** and similar mmw circuitry **130**. The mmw circuitry **130** further may also comprise a Yagi antenna to emit the mmw signal **132**. In comparison to the electronic device **200**, the electronic device **500** does not exhibit a (dielectric) lens.

As can be seen from a comparison of FIG. **5***a* and FIG. **5***c*, e.g., the radiation patterns **136-1**, **136-2**, **136-3**, and **136-4** differ from the radiation pattern **136-5**. In particular, the radiation patterns **136-1**, **136-2**, **136-3**, and **136-4** may at least partly exhibit a higher intensity of the mmw signal **132** on the second side **102** than **136-5**. For example, the radiation pattern **136-2** has a higher intensity at a radiation angle of −25° in the vertical plane than the radiation pattern **136-5**. Similarly, it can be seen from a comparison of FIGS. **5***b* and **5***d* that the radiation pattern **136-2** has a higher intensity than the radiation pattern **136-5** at the radiation angle of 5° in the horizontal plane. Hence, the radiation patterns **136-1**, **136-2**, **136-3**, and **136-4** may enable at least at some radiation angles a higher accuracy and/or reliability in environment, object, movement, and/or gesture sensing than the radiation pattern **136-5**. In particular, the radiation patterns **136-1**, **136-2**, **136-3**, and **136-4** enabled by the dielectric lens **112** may allow a more reliable and/or precise sensing of objects, the environment, movements, and/or gestures on the second side **102**.

The skilled person will understand that the above proposed architecture may also enable a more reliable and/or more precise sensing of the environment, objects, movements, and/or gestures using another lens type (e.g. a biconvex lens or a compound lens), other shapes of the dielectric lens **112**, other (transmissive, dielectric) materials for the dielectric lens **112**, another radius for the dielectric lens **112**, different antennas (e.g. a slot antenna), and/or a different positioning of the dielectric lens **112**, the mmw circuitry **130** and/or the electrically conductive layer **120** to each other.

A flow chart of an equivalent method **600** for the electronic devices **100** and/or **200**, which exhibit a housing and an electrically conductive layer, is illustrated in FIG. **6**.

Method **600** comprises emitting **610** a mmw signal using a mmw circuitry arranged in the housing and on a first side of the electrically conductive layer. Further, method **600** comprises refracting **620** at least a part of the mmw signal outside the housing towards a second side opposite to the first side of the electrically conductive layer using a portion of the housing which is configured as dielectric lens.

As described above, the electrically conductive layer may block the mmw signal at least partially due to its electrical properties. The dielectric lens, e.g., is formed in an outer portion of the housing, which may at least partially be arranged on the first side and protrude over an outer edge of the electrically conductive layer to deflect the mmw signal around the electrically conductive layer. For the details, it is referred to the above description of the electronic devices **100** and **200**.

The examples described herein can be summarized as follows:

Some examples relate to an electronic device. The electronic device comprises a housing, an electrically conductive layer, and millimeter-wave, mmw, circuitry. The mmw circuitry is configured to emit a mmw signal. The mmw circuitry is arranged in the housing and on a first side of the electrically conductive layer. The housing has at least one portion configured as a dielectric lens to refract the mmw signal at least partially outside the housing towards a second side opposite to the first side of the electrically conductive layer.

According to some examples, the dielectric lens is configured to refract reflections of the mmw signal at least partially from the second side towards the mmw circuitry. Also, the mmw circuitry may be further configured to receive the reflections.

In some examples, the electronic device further comprises a data processing circuitry configured to detect movements of a user on the second side of the electrically conductive layer using the reflections.

According to some examples, the dielectric lens is formed by all or part of an edge portion of the housing.

In some examples, the dielectric lens is at least partly arranged on the first side of the electrically conductive layer and at least partially protrudes over an edge of the electrically conductive layer.

According to some examples, the mmw circuitry is attached to the dielectric lens.

In some examples, the dielectric lens is a convex lens.

According to some examples, the dielectric lens is a plano-convex lens. Also, the mmw circuitry may be attached to a planar face of the plano-convex lens.

In some examples, an optical axis of the dielectric lens is parallel to the electrically conductive layer.

According to some examples, a refractive exterior surface of the dielectric lens has a radius between 3 mm and 7 mm.

In some examples, the electronic device further comprises a touchscreen. Also, the electrically conductive layer may form a part of the touchscreen for sensing touches.

According to some examples, the touchscreen is framed in the housing.

In some examples, the mmw signal has a frequency between 30 GHz and 300 GHz.

According to some examples, the mmw circuitry comprises at least one slot antenna configured to emit the mmw signal.

In some examples, the mmw circuitry comprises at least one Yagi antenna to emit the mmw signal.

Some examples relate to a method for an electronic device, wherein the electronic device comprises a housing and an electrically conductive layer. The method comprises emitting a mmw signal using a mmw circuitry arranged in the housing and on a first side of the electrically conductive layer. The method also comprises refracting at least a part of the mmw signal outside the housing towards a second side opposite to the first side of the electrically conductive layer using a portion of the housing configured as dielectric lens.

The aspects and features described in relation to a particular one of the previous examples may also be combined with one or more of the further examples to replace an identical or similar feature of that further example or to additionally introduce the features into the further example.

Examples may further be or relate to a (computer) program including a program code to execute one or more of the above methods when the program is executed on a computer, processor or other programmable hardware component. Thus, steps, operations or processes of different ones of the methods described above may also be executed by programmed computers, processors or other programmable hardware components. Examples may also cover program storage devices, such as digital data storage media, which are machine-, processor- or computer-readable and encode and/or contain machine-executable, processor-executable or computer-executable programs and instructions. Program storage devices may include or be digital storage devices, magnetic storage media such as magnetic disks and magnetic tapes, hard disk drives, or optically readable digital data storage media, for example. Other examples may also include computers, processors, control units, (field) programmable logic arrays ((F)PLAs), (field) programmable gate arrays ((F)PGAs), graphics processor units (GPU), application-specific integrated circuits (ASICs), integrated circuits (ICs) or system-on-a-chip (SoCs) systems programmed to execute the steps of the methods described above.

It is further understood that the disclosure of several steps, processes, operations or functions disclosed in the description or claims shall not be construed to imply that these operations are necessarily dependent on the order described, unless explicitly stated in the individual case or necessary for technical reasons. Therefore, the previous description does not limit the execution of several steps or functions to a certain order. Furthermore, in further examples, a single step, function, process, or operation may include and/or be broken up into several sub-steps, -functions, -processes or -operations.

If some aspects have been described in relation to a device or system, these aspects should also be understood as a description of the corresponding method. For example, a block, device or functional aspect of the device or system may correspond to a feature, such as a method step, of the corresponding method. Accordingly, aspects described in relation to a method shall also be understood as a description of a corresponding block, a corresponding element, a property or a functional feature of a corresponding device or a corresponding system.

The following claims are hereby incorporated in the detailed description, wherein each claim may stand on its own as a separate example. It should also be noted that although in the claims a dependent claim refers to a particular combination with one or more other claims, other examples may also include a combination of the dependent claim with the subject matter of any other dependent or independent claim. Such combinations are hereby explicitly proposed, unless it is stated in the individual case that a particular combination is not intended. Furthermore, features of a claim should also be included for any other independent claim, even if that claim is not directly defined as dependent on that other independent claim.

What is claimed is:

1. An electronic device comprising:

a housing;

an electrically conductive layer; and

millimeter-wave (mmw) circuitry comprising an antenna configured to emit a mmw signal in a direction parallel to the electrically conductive layer, and signal generation circuitry configured to generate the mmw signal, wherein the mmw circuitry is arranged in the housing, and located at a first side of the electrically conductive layer,

wherein the housing comprises at least one portion configured as a dielectric lens to refract the mmw signal from the first side of the electrically conductive layer towards a second side of the electrically conductive layer opposite to the first side of the electrically conductive layer, wherein the mmw circuitry is located completely behind the electrically conductive layer at the first side of the electrically conductive layer with respect to the second side of the electrically conductive layer,

wherein the dielectric lens extends over a portion of the electrically conductive layer at a corner of the housing, at least a portion of the dielectric lens has an unobstructed view of the second side of the electrically conductive layer in a direction perpendicular to the electrically conductive layer, and the dielectric lens is configured to change a direction of the mmw signal from the direction parallel to the electrically conductive layer to the direction perpendicular to the electrically conductive layer.

2. The electronic device of claim **1**, wherein the dielectric lens is configured to refract reflections of the mmw signal at least partially from the second side towards the mmw circuitry, and wherein the mmw circuitry is further configured to receive the reflections.

3. The electronic device of claim **2**, further comprising data processing circuitry configured to detect movements of a user on the second side of the electrically conductive layer using the reflections.

4. The electronic device of claim **1**, wherein the dielectric lens is formed by all or part of an edge portion of the housing.

5. The electronic device of claim **1**, wherein the dielectric lens is at least partly arranged on the first side of the electrically conductive layer and at least partially protrudes over an edge of the electrically conductive layer.

6. The electronic device of claim **1**, wherein the mmw circuitry is attached to the dielectric lens.

7. The electronic device of claim **1**, wherein the dielectric lens is a convex lens.

8. The electronic device of claim **1**, wherein the dielectric lens is a plano-convex lens, and wherein the mmw circuitry is attached to a planar face of the plano-convex lens.

9. The electronic device of claim **1**, wherein an optical axis of the dielectric lens is parallel to the electrically conductive layer.

10. The electronic device of claim **1**, wherein a refractive exterior surface of the dielectric lens comprises a radius between 3 mm and 7 mm.

11. The electronic device of claim **1**, further comprising a touchscreen for sensing touches, wherein the electrically conductive layer forms a part of the touchscreen.

12. The electronic device of claim **1**, wherein the mmw signal has a frequency between 30 GHz and 300 GHz.

13. The electronic device of claim **1**, wherein the mmw circuitry comprises at least one slot antenna configured to emit the mmw signal.

14. The electronic device of claim **1**, wherein the mmw circuitry comprises at least one Yagi antenna to emit the mmw signal.

15. The electronic device of claim **1**, wherein the dielectric lens is directly attached to the mmw circuitry via an adhesive disposed within a signal path of the mmw signal, and the adhesive is at least partly transmissive for the mmw signal.

16. A method for an electronic device comprising a housing and an electrically conductive layer, the method comprising:

generating and emitting a millimeter-wave (mmw) signal using a mmw circuitry comprising generation circuitry configured to generate the mmw signal, and an antenna arranged in the housing and on a first side of the electrically conductive layer; and

refracting the mmw signal from the first side of the electrically conductive layer towards a second side of the electrically conductive layer opposite to the first side of the electrically conductive layer using a portion of the housing configured as a dielectric lens, wherein the mmw circuitry is located completely behind the electrically conductive layer at the first side of the electrically conductive layer with respect to the second side of the electrically conductive layer, and refracting comprises changing a direction of the mmw signal from the direction parallel to the electrically conductive layer to the direction perpendicular to the electrically conductive layer, and

wherein the dielectric lens extends over a portion of the electrically conductive layer at a corner of the housing, and at least a portion of the dielectric lens has an unobstructed view of the second side of the electrically conductive layer in a direction perpendicular to the electrically conductive layer.

17. The method of claim **16**, further comprising:

refracting a reflected mmw signal using the portion of the housing configured as the dielectric lens; and

receiving the refracted reflected mmw signal using the mmw circuitry.

18. The method of claim **16**, wherein the dielectric lens is directly attached to the mmw circuitry via an adhesive disposed within a signal path of the mmw signal, and the adhesive is at least partly transmissive for the mmw signal.

19. A touchscreen system comprising:

a touchscreen display comprising an electrically conductive layer, the touchscreen display comprising a region configured to sense a disturbance of an electric field when a user touches the touchscreen display on a first surface disposed on a front side of the electrically conductive layer;

millimeter-wave (mmw) radar circuitry comprising signal generation circuitry configured to generate a mmw signal, and an antenna disposed on a back side of the electrically conductive layer opposite the front side; and

a dielectric lens disposed at an edge portion of the touchscreen display, the dielectric lens configured to refract the mmw signal generated by the mmw radar circuitry from the back side of the electrically conductive layer towards the front side of the electrically conductive layer, wherein the mmw radar circuitry is located completely behind the electrically conductive layer at the back side of the electrically conductive layer with respect to the front side of the electrically conductive layer, and

wherein the dielectric lens extends over a portion of the electrically conductive layer, at least a portion of the dielectric lens has an unobstructed view of the back side of the electrically conductive layer in a direction perpendicular to the electrically conductive layer, and the dielectric lens is configured to change a direction of the mmw signal from the direction parallel to the electrically conductive layer to the direction perpendicular to the electrically conductive layer.

20. The touchscreen system of claim **19**, further comprising data processing circuitry coupled to the mmw radar circuitry, the data processing circuitry configured to detect movements of the user on the front side of the electrically conductive layer via the refracted mmw signal.

21. The touchscreen system of claim 19, wherein the dielectric lens is a plano- convex lens, and wherein the mmw radar circuitry is attached to a planar face of the plano-convex lens.

22. The touchscreen system of claim 19, wherein an optical axis of the dielectric lens is parallel to the electrically conductive layer.

23. The touchscreen system of claim 19, wherein the dielectric lens is directly attached to the mmw circuitry via an adhesive disposed within a signal path of the mmw signal, and the adhesive is at least partly transmissive for the mmw signal.

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